Effects of soil moisture and temperature on CH_4 oxidation and N_2O emission of forest soil

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Abstract: Soil samples were taken from depth of 0-12 cm in the virgin broad- leaved/Korean pine mixed forest in Changbai Mountain in April, 2000. 20 $\mu L \cdot L^{-1}$ and 200 $\mu L \cdot L^{-1}$ CH_4 and N_2O concentration were supplied for analysis. Laboratory study on CH_4 oxidation and N_2O emission in forest soil showed that fresh soil sample could oxidize atmospheric methane and product N_2O. Air-dried soil sample could not oxidize atmospheric methane, but could product N_2O. However, it could oxidize the supplied methane quickly when its concentration was higher than 20 $\mu L \cdot L^{-1}$. The oxidation rate of methane was increased with its initial concentration. An addition of water to dry soil caused large pulse of N_2O emissions within 2 hours. There were curvilinear correlations between N_2O emission and temperature (r^2 =0.706, $p < 0.05$), and between N_2O emission and water content (r^2 =0.2968, $p < 0.05$). These suggested temperature and water content were important factors controlling N_2O emission. The correlation between CH_4 oxidization and temperature was also found while CH_4 was supplied 200 $\mu L \cdot L^{-1}$ (r^2 =0.3573, $p < 0.05$). Temperature was an important factor controlling CH_4 oxidation. However, when 20 $\mu L \cdot L^{-1}$ CH_4 was supplied, there was no correlation among CH_4 oxidization, N_2O emission, temperature and water content.
Key words: Air-dried soil; Fresh forest soil; CH_4 oxidation; N_2O emission
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Introduction

Methane (CH_4) and Nitrous oxide (N_2O) are two important greenhouse gases that also play an important role in photochemical reactions in atmosphere.

The global warming potential of CH_4 and N_2O are estimated to be about 62 and 290 times that of carbon dioxide respectively. The concentration of these gases have been increasing rapidly since the start of the industrial age, currently at rate of about 1% and 0.25% per year respectively (Lelieveld *et al.* 1993), and 70%-90% of these gases is of biogenic origin (Bouwman 1990). From the estimate of known global source and sinks of N_2O made by IPCC (1992), the emission from temperate forests was 2.2-3.7 $Tg \cdot a^{-1}$. Total amount of atmospheric CH_4 consumed by aerobic soils ranged from 15 to 45 $Tg \cdot a^{-1}$, which is about 3% to 10% of the global emissions (Watson *et al.* 1992). Forest ecosystem may function as a significant source for atmospheric N_2O and as a significant sink for atmospheric CH_4 within terrestrial ecosystems.

Past ten years and more, soil and environment scientists have observed N_2O emission and CH_4 uptake from forest soil, and have done much on various factors controlling them, such as soil temperature, soil moisture, soil redox potential, soil pH, the kind of fertilizer used, and ecotype, etc. All of these soil variables show a high spatial and temporal variability. Soil moisture and temperature fluctuate rapidly according to weather condition. It is likely that the variability influence not only CH_4 uptake but also N_2O emission. However, up to now, there is very little laboratory investigation on it with forest soil in China. In this paper, the effects of temperature and moisture on CH_4 oxidization and N_2O emission from a broad-leaved/Korean pine mixed forest in Changbai Mountain were studied in laboratory.

Materials and methods

The sample plot were located in the virgin broad-leaved /Korean pine mixed forest, at altitude of 736 m in Changbai Mountain (42°24′ N, 128°28′ E), where annual mean precipitation is 700-800 mm. The type forest soil is mountain dark brown forest soil.

Soil sampling was taken from depth of 0~12 cm on April 18, 2000. Soil water content is 82%. NH_4^+-N

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and NO_3^--N contents are 2.11 μg·g^{-1} and 3.17 μg·g^{-1} respectively, Soil pH 5.8 (0.01 mol $CaCl_2$)/6.8 (H_2O).

Fresh soil was air-dried, sieved (1 mm), moisture is 6.1%. After air-dried, soil NH_4^+-N and NO_3^--N contents are 1.18 μg· g^{-1} and 1.57 μg·g^{-1} respectively.

Random design, 2 factors and 4 levels (temperature: 4 °C, 15 °C, 25 °C, 35 °C, moisture: 30%, 50%, 70%, 90% (g H_2O /g dry soil) was used in the experiment.

The effects of moisture and temperature on N_2O emission and CH_4 oxidize were examined by moistening air-dried soil to four different water contents 30%, 50%, 70%, 90% (g H_2O/g dry soil) and moistening soil were incubated at 4 °C, 15 °C, 25 °C, 35 °C in dark. Three replicates were established for per combination. Each replicate contains three treatments (atmospheric methane, 20 μL·L^{-1}CH_4, 200 μL·L^{-1} CH_4).

Incubation procedure: 23 g sample (dry weight equivalent) were brought to four different moistures with distilled water, and placed into 300 mL bottles, each bottle was sealed with rubber stopper. In treatments with supplied CH_4, CH_4 were injected to headspace in which CH_4 concentration reached 20 μL·L^{-1} and 200 μL·L^{-1}, respectively, the bottles were kept steady in 4 °C, 15 °C, 25 °C, 35 °C respectively. After initial sampling, the incubation lasted for 12 hours for analyzing N_2O and CH_4 concentration in the headspace of the bottles by GC method.

N_2O concentrations were measured with Shimadzu GC-14A equipped with ECD. Detector, oven and injector temperature were 300 °C, 60 °C, and 100 °C respectively. A Shimadzu GC-14B equipped with FID was used for CH_4 measurement. Detector, oven and injector temperatures were 180 °C, 140 °C, and 100 °C respectively.

Results and discussion

The effect of CH_4 concentration on CH_4 oxidization of air-dried forest soil

Air-dried forest soil could not oxidize atmospheric methane (result is not listed), but could oxidize the supplied methane quickly when its concentration was higher than 20 μL·L^{-1}. The oxidation rate of methane was increased with its initial concentration. At 200 μL·L^{-1} CH_4 the oxidation rate was about 11 times higher than that at 20 μL·L^{-1} (Fig.1).

Air-dried soil may destroy activity of CH_4 oxidizer. A minimum of soil water is necessary to maintain the physiological functions of the bacteria whose cell water contents keeps between 233%~560% H_2O dry weigh. Below 8% soil moisture no CH_4 oxidation activity was detected both in the induction experiment and in induced soils (Bender 1995).

There was difference in supplied CH_4 concentration, which needs to be inducting CH_4 oxidation process in different soils. Yuan Yanxiao *et al.* (1997) found that when paddy soil CH_4 concentration is above 10 μL·L^{-1} the paddy soil can oxidize CH_4. Bender (1995) reported when supplied CH_4 concentration is below 100 μL·L^{-1}, paddy soil showed no induced CH_4 oxidization at all. The induction of CH_4 oxidation activity was primarily dependent on CH_4 mixing ratio at the beginning of the incubation (Bender 1995). Therefore, the measured increase of the CH_4 oxidation activity was due to an increase of the size of the methanotrophic population or an increase of the activity of the resident population.

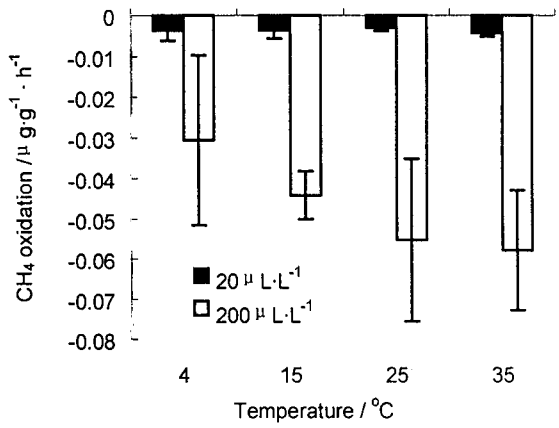

Fig. 1. CH_4 oxidation of soil when it was supplied with 20 μL· L^{-1} and 200 μL· L^{-1}CH_4

The effect of temperature and moisture on N_2O emission from air-dried forest soil

An addition of water to air-dried forest soil could result in quick increase of N_2O flux within 2 hours, but there is strong linear positive correlation with soil moisture (Fig.2).

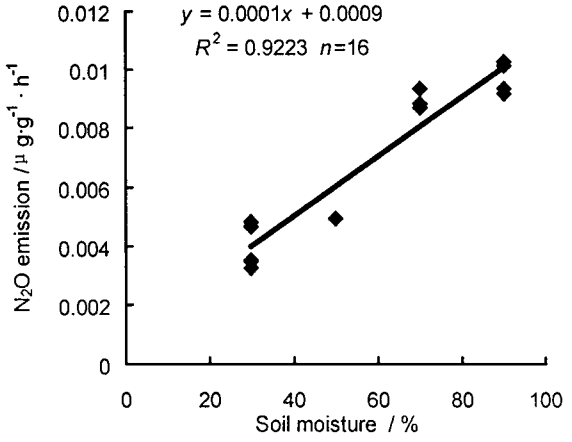

Fig. 2. The relationship between N_2O emission and soil moisture after air-dried soil was moistened within 2 hours

When supplied CH_4 concentration was 20 $\mu L \cdot L^{-1}$, linear regression showed there was no correlation between N_2O emission and moisture, temperature respectively.

At supplied CH_4 concentration was 200 $\mu L \cdot L^{-1}$, there was a curvilinear relationship between N_2O emission and temperature ($r^2 = 0.706$, $p < 0.05$) (Fig. 3A).

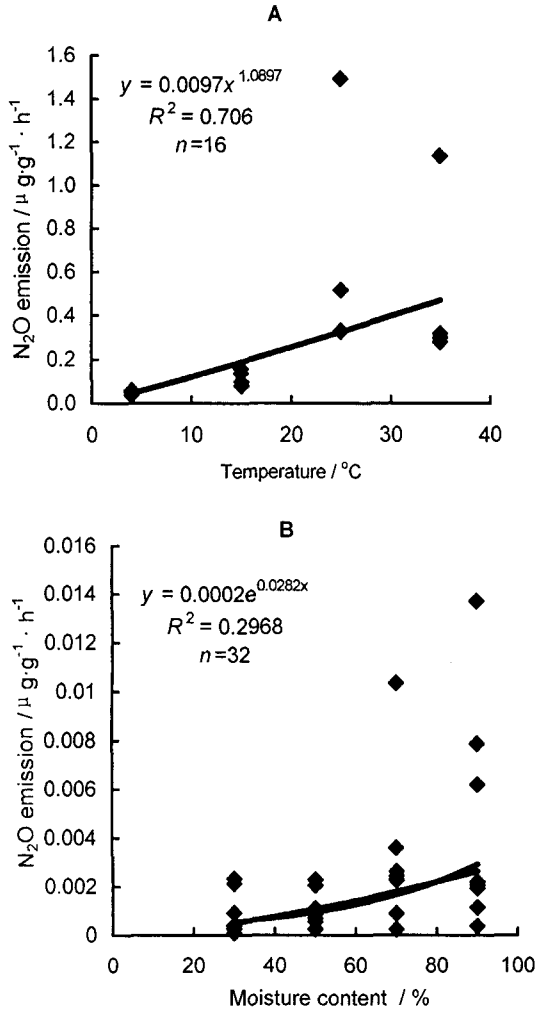

Fig. 3. Effects of temperature and soil moisture on N_2O emission from soil supplied with 200 $\mu L \cdot L^{-1}$ CH_4 (A) and both 20 and 200 $\mu L \cdot L^{-1}$ CH_4 (B)

When supplied CH_4 concentration was 20 $\mu L \cdot L^{-1}$ and 200 $\mu L \cdot L^{-1}$, linear regression showed there was a curvilinear correlation N_2O emission with moisture ($r^2 = 0.2968$, $p < 0.05$) (Fig. 3B).

Production of N_2O was measured from soil samples maintained at four moisture levels. The results showed that only small amounts of N_2O were detected at the lowest moisture level (30%), as moisture was raised, production of N_2O increased, and maximum N_2O emission occurred at 90%. A curvilinear correlation N_2O emission with moisture contents was found. This observation was consisted with the result of Knowles. Knowles (1982) suggested that biological denitrification occur only at moisture levels greater than 60%, high moisture levels reduce oxygen within the soil, thus inducing anaerobic conditions.

The N_2O flux showed significant linear positive correlation with soil moisture contents ($r^2 = 0.9223$, $p < 0.01$). This indicates that N_2O production is controlled by soil moisture (Rickard 1988). Increased N mineralization following wetting of dry soil is generally thought to be due to the release of readily-decomposable organic matter into the soil environment from non-living organic matter and from the death of the microbial population after stress from desiccation. Christenson (1990) found that addition of dead bacterial cell to an anaerobic soil slurry doubled denitrification activity within 2 hours, and following a wetting event, carbon and nitrogen availability is often high (Smith *et al.* 1985).

The effect of temperature and of water contents on CH_4 oxidation from air-dried forest soil

When supplied CH_4 concentration was 20 $\mu L \cdot L^{-1}$, linear regression results showed there was no correlation between CH_4 oxidation and moisture, and temperature.

When supplied CH_4 concentration was 200 $\mu L \cdot L^{-1}$, a curvilinear relationship between CH_4 and temperature was found ($r^2 = 0.406$, $p < 0.05$) (Fig. 4)

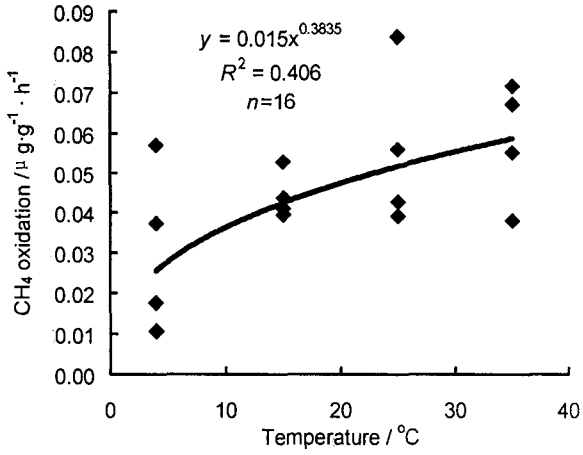

Fig. 4. The relationship between CH_4 oxidation and temperature at CH_4 concentration 200 $\mu L \cdot L^{-1}$

Soil temperature appears to be an important controller of CH_4 consumption atslow temperatures (-5 °C to 10 °C), but CH_4 consumption was independent of soil temperature between 10-20 °C (Castro 1995). Xu Hui (1999) reported no significant

Xu Hui (1999) reported no significant correlation was found between CH_4 uptake and temperature. Our results suggested CH_4 oxidizers were insensitive to temperature between 4 °C ~35 °C at 20 $\mu L \cdot L^{-1} CH_4$ concentration, but at supplied CH_4 concentration 200 $\mu L \cdot L^{-1}$, the influence of the temperature on CH_4 oxidizers became more important.

Dobbie (1996) found that in arable soil, CH_4 oxidation rate was related to soil moisture contents only in dry summer conditions. Whalen *et al.* (1990) observed that CH_4 oxidation in a landfill cover soil was both moisture and temperature dependent, with an optimum moisture contents for oxidation of 11%. Czepiel *et al.* (1995) also found an optimum water contents at which CH_4 oxidation occurred, but the value varied between different soil samples. When WFPS of soil was higher proportion, the temperature was the most important variable. Our results supported the results of Czepiel.

Conclusion

The laboratory study results showed that air-dried soil sample can't oxidize atmospheric methane, and can product N_2O, but can oxidize the supplied methane quickly when its concentration was higher than 20 $\mu L \cdot L^{-1}$. The oxidation rate of methane was increased with its initial concentration. Wetting soil caused large pulse of N_2O emissions within 2 hours. There was a curvilinear correlation between N_2O emission and temperature (r^2 =0.706, $p < 0.05$), and also between N_2O emission and water contents (r^2 = 0.2968, $p < 0.05$), and the correlation between CH_4 oxidization and temperature while supplied CH_4 is 200 $\mu L \cdot L^{-1}$ (r^2 =0.406, $p < 0.05$). However, when 20 $\mu L \cdot L^{-1}$ CH_4 was supplied, there was no correlation among CH_4 oxidization, N_2O emission, temperature and soil water contents.

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